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Final Report on Tasks 1, 2, 5, 6

July 1986

Prepared for:
NASA Headquarters
Office of Space Science and Applications
Code EC, John Kiebler
Washington, D.C. 20546

Contract Number: NASW-3973

Prepared by Douglas Boyd and Tom Tillotson

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Final Report on Tasks 1, 2, 5, 6

NASA Contract NASW - 3973

This report documents and summarizes interim results of tasks 1, 2, 5, and 6 performed under NASA contract NASW - 3973, a cost plus fixed fee, level of effort type contract for remote sensing frequency sharing studies. The effective date of the contract was August 1, 1984. The contract is funded through July 31,1985. The final report on all Tasks is due July 31, 1986.

The following Tasks are discussed in the remainder of this report:

Task 1- Adjacent and Harmonic Band Analysis

Task 2- Analysis of Impact of Sensor Resolution on Interference

Task 5- Develop Performance Criteria, Interference Criteria, Sharing Criteria, and Coordination Criteria

Task 6- Spectrum Engineering for NASA Microwave Sensor Projects

Appendix A contains complete task descriptions taken directly from the contract.

1. Task 1 Adjacent and Harmonic Band Analysis

A final report on Task 1 entitled "Interference to Remote Passive Microwave Sensors from Active Services in Adjacent and Subharmonic Bands", SGC, April 1985, has been delivered to Mr. John W. Kiebler, NASA Headquarters. The purpose of this report is to present the results of analyses to determine the compatability between remote passive microwave sensors and active services in adjacent and subharmonic bands.

This has included identifying frequency allocations for remote passive sensing, determining typical sensor and interferer characteristics, and developing a model suitable for the quantization and assessment of the cummulative interference.

1.1 Sensor Characteristics

A list of recommended sensing characteristics is presented in CCIR Report 693-1 and 694-1. Determined from these reports and the outcome of the 1979 World Administrative Radio Conference are the sensing bands and characteristics presented in Table 1. The interference thresholds are defined in Report 694-1 as 20% of the minimum discernable power change and the attenuation constants are taken from CCIR SG 5, Report 719-1.

Antennas used on remote sensors are assumed to be high efficiency pencil beam antennas with the mainbeam providing a beamwidth narrow enough to meet resolution requirements. A model of such an

Table 1. Sensor Data

SENSOR FREQUENCY Lower - Upper	SENSOR BANDWIDTH	RECEIVER POLES	SENSOR RESOLUTION	INTERFERENCE THRESHOLD	ATTENUATION Oxygen	Water
GHz	MHz		km	dBW	dB/km	
1.400-1.427	15.0	4	20.0	-171.0	0.0000	0.0000
4.200-4.400	200.0	4	2.0	-158.0	0.0065	0.0000
6.425-7.075	200.0	4	20.0	-158.0	0.0068	0.0000
6.425-6.625	200.0	4	20.0	-158.0	0.0068	0.0000
6.875-7.075	200.0	4	20.0	-158.0	0.0068	0.0000
10.600-10.700	100.0	4	1.0	-156.0	0.0073	0.0090
15.200-15.400	200.0	4	2.0	-160.0	0.0078	0.0180
18.600-18.800	200.0	4	2.0	-152.0	0.0084	0.0430
21.200-21.400	200.0	4	2.0	-160.0	0.0104	0.1600
22.210-22.500	290.0	4	2.0	-155.0	0.0109	0.1500
23.600-24.000	400.0	4	2.0	-157.0	0.0120	0.1200
31.300-31.800	500.0	4	2.0	-156.0	0.0180	0.0700
36.000-37.000	1000.0	4	1.0	-146.0	0.0430	0.0830
50.200-50.400	200.0	4	10.0	-157.0	0.9000	0.0140
51.400-59.000	200.0	4	10.0	-157.0	15.0000	0.1600
51.400-51.600	200.0	4	10.0	-157.0	15.0000	0.1600
58.800-59.000	200.0	4	10.0	-157.0	15.0000	0.1600
64.000-65.000	200.0	4	10.0	-157.0	2.3000	0.2300
64.000-64.200	200.0	4	10.0	-157.0	2.3000	0.2300

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64.800-65.000	200.0	4	10.0	-157.0	2.3000	0.2300
86.000-92.000	6000.0	4	1.0	-138.0	0.0480	0.4150
100.000-102.000	2000.0	4	1.0	-150.0	0.0350	0.5200
105.000-126.000	2000.0	4	1.0	-150.0	0.0465	0.0610
105.000-107.000	2000.0	4	1.0	-150.0	0.0465	0.0610
124.000-126.000	2000.0	4	1.0	-150.0	0.0465	0.0610
150.000-151.000	2000.0	4	1.0	-150.0	0.0154	1.2500
164.000-168.000	2000.0	4	1.0	-150.0	0.0125	2.3000
182.000-185.000	2000.0	4	1.0	-150.0	0.0120	10.0000
217.000-231.000	2000.0	4	1.0	-150.0	0.0088	2.7500
275.000-277.00	2000.0	4	1.0	-150.0	0.0070	5.1000

antenna is presented in Report 850 and appears in Figure 1 along with the respective equations for calculating gain based on the assumptions in this report. The model assumes 90% of the received power is from the mainbeam, 7% from the first sidelobe, which has a beamwidth five times the mainbeam beamwidth, 2% from the second sidelobe, and 1% from the backlobe. The mainbeam beamwidth is determined from the required resolution and the orbit altitude. Gain is determined by the ratio of percent of power to the percent of spherical area in the beam.

Input or RF filters are not used on sensors because of the extremely low power levels being detected. Input passband characteristics are then determined by the IF bandwidth, antenna, antenna switch, and waveguide characteristics. It is estimated that the input passband of a typical sensor can be modeled by a 4 pole Butterworth passband characteristic. If both the receiver passband and the interferer spectrum are modeled by a Butterworth characteristic, an out-of-band rejection factor (OBRF) can be defined as:

$$\mathrm{OBRF} = \frac{\int_{-\infty}^{\infty} A^2(f)\, B(f)\, dw}{\int_{-\infty}^{\infty} B(f)\, dw}$$

where A(f) is the normalized receiver amplitude response, B(f) is the normalized interference spectrum, and:

$$A^2(f) = \frac{1}{\left(\frac{f-f_r}{\pi B_r}\right)^{2N_r} + 1}$$

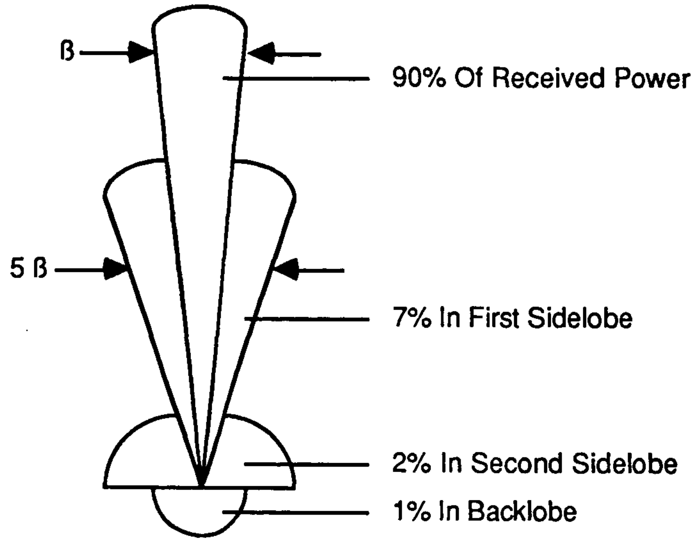
$$B(f) = \frac{1}{\left(\frac{f-f_i}{\pi B_i}\right)^{2N_i} + 1}$$

where B_r is the -3 dB bandwidth, N_r is the number of poles and f_r is the center frequency in the receiver Butterworth characteristic. Similarly, B_i is the -3 dB bandwidth, N_i is the number of poles and f_i is the center frequency in the interferer spectrum. When implementing these integrals using numerical techniques the receiver was assumed to have a maximum filter rejection of 70 dB and all the interferer power was assumed to be contained within ± 10 times the interferer bandwidth. Figure 2 shows the relationship between the OBRF, the number of receiver poles, and the guard band (band edge to band edge) for a single interferer.

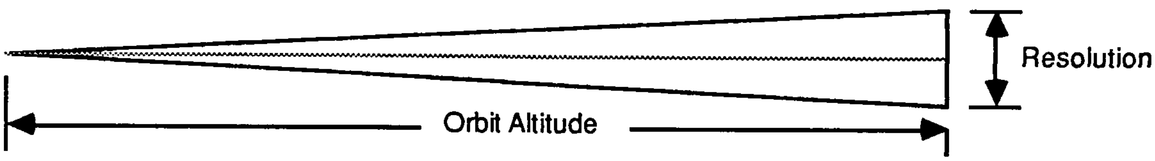
An out-of-band rejection factor can be determined for an adjacent band containing a large number of interferers by calculating the OBRF for each channel, or, to conserve computation time, by interpolating between points used to produce the curves in Figure 2. A new set of curves must be generated for a different combination of receiver and interferer bandwidths.

1.2 Interferer Characteristics

Data required to characterize the typical station classes in an interfering band include bandwidth, transmit power, mainlobe gain, number of units, and, allocated band within which all units of the particular station class can be found. Values of these parameters should be chosen to best represent all assignments.



ß = Angle Which Gives Required Resolution From Orbit.



$$\beta = 2 \tan^{-1}\left(\frac{\text{Resolution}}{(2)\ (\text{Orbit Altitude})}\right)$$

$$\text{Gain} = 10 \log \left[\frac{4\pi\,(\text{fraction of power in beam})}{\text{area of beam on unit circle}}\right]$$

$$\text{Mainlobe Gain} = 10 \log \left[\frac{4\pi(.9)}{2\pi\,(1 - \cos\beta/2)}\right] = 10 \log \left[\frac{1.8}{1 - \cos\beta/2}\right]$$

$$\text{Firstlobe Gain} = 10 \log \left[\frac{4\pi(.07)}{2\pi\,(\cos\beta/2 - \cos5\beta/2)}\right] = 10 \log \left[\frac{.14}{\cos\beta/2 - \cos5\beta/2}\right]$$

$$\text{Second Sidelobe Gain} = 10 \log \left[\frac{4\pi(.01)}{2\pi\,(\cos5\beta/2)}\right] = 10 \log \left[\frac{.04}{\cos5\beta/2}\right]$$

$$\text{Backlobe Gain} = 10 \log \left[\frac{4\pi(.01)}{2\pi}\right] = -16.99\ \text{dB (Constant)}$$

Figure 1. Sensor Antenna Model

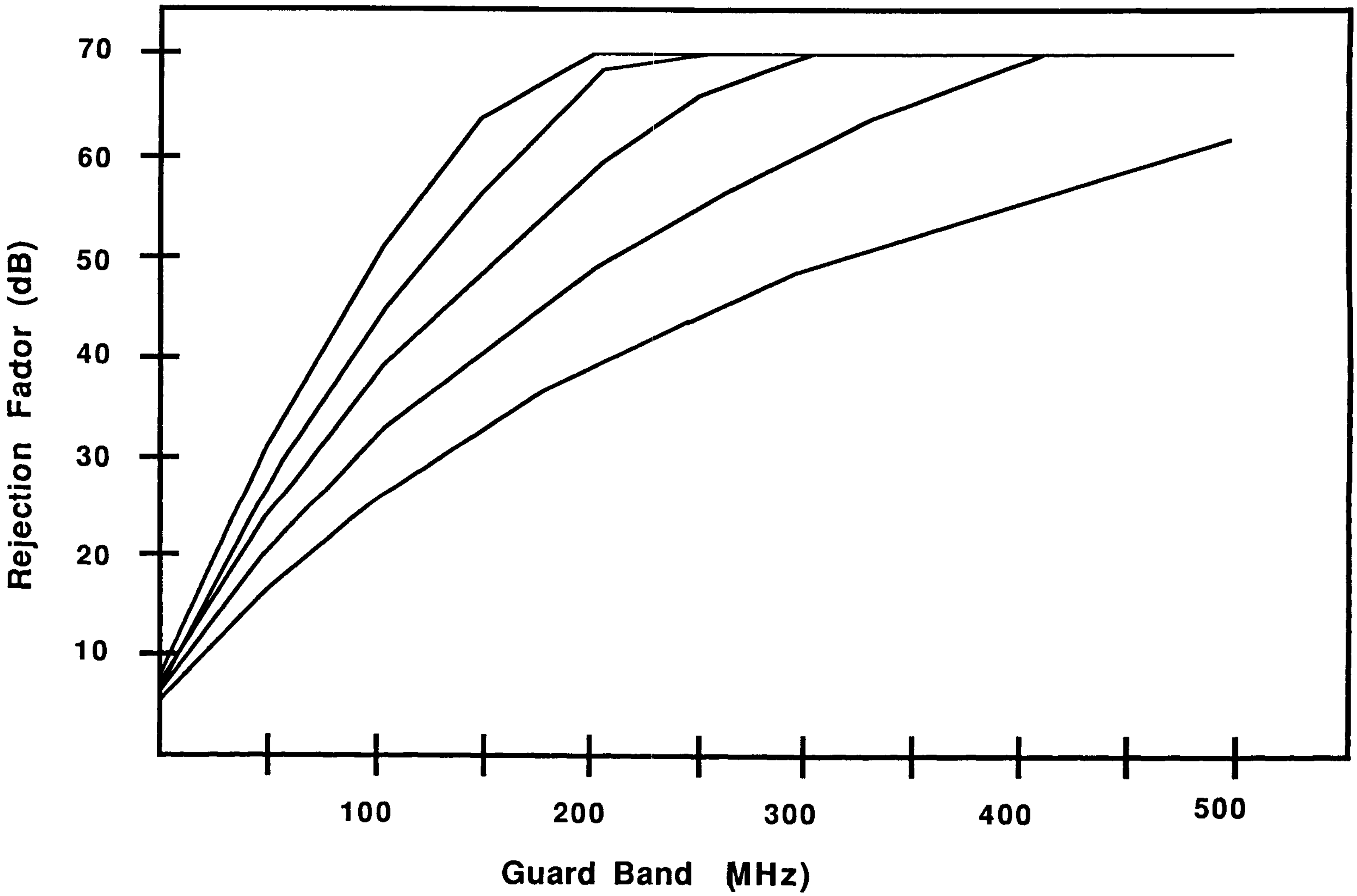


Figure 2. Out of Band Rejection Factor for a 20 MHz Bandwidth Interferer

(200 MHz bandwidth receiver with 4 to 8 pole Butterworth filter characteristic; interferer spectrum modeled by 3 pole butterworth filter characteristics)

Knowing the mainlobe gain of a particular station class, sidelobe gains can be predicted with the patterns given in CCIR Report 391-4.

Harmonic output from interfering stations can be predicted from the Table of Maximum Permitted Spurious Emission Power Levels in Appendix 8 of the Radio Regulations. Because of the uncertainty in predicting interferer characteristics at high harmonics, especially those of antennas, this study was limited to the first two subharmonics of the sensing bands. The gain of antennas up to the second harmonic was assumed to be a constant because of the offsetting nature of the increased antenna diameter (measured in wavelengths), the increased antenna surface tolerance losses, and the decreased antenna feed efficiencies with increasing frequency.

After reviewing I.T.U. and domestic U.S. regulations it was determined that a 3 pole Butterworth characteristic would best represent the interferer spectrum for out-of-band emissions. Further, it was determined by subsequent calculations that for any case in which the sensor bandwidth is wider than the interferer bandwidth by a factor of five or more, the received interference power is nearly independent of the number of poles used in the interferer spectrum model. This ratio of five to one or more is true for all of the bands above 1400 MHz. In the 1400 MHz band the dominant interference is from subharmonic bands rather than adjacent bands so that the number of poles in the interferer spectrum has only a small effect in this band as well. The number and characteristics of interferers used in the analysis were determined from statistics compiled from the frequency assignments in the U.S.

1.3 Interference Models

This report analyses interference levels into passive sensors from both terrestrial stations and space stations using techniques similar to those in CCIR Report 694-1. Interference from terrestrial stations is computed using a uniform distribution model.

1.3.1 Uniform Distribution Computer Model

Single entry interference into the the sensor mainlobe and first sidelobe is determined separately from cummulative interference into the second sidelobe because of the sensor's high resolution.

For mainlobe and first sidelobe interference, corresponding to a direct overflight by the sensor, an area lost can be defined as the set of all subsatellite points for which interference is experienced. For mainlobe interference the area lost corresponds to the area of the mainlobe on the surface of the earth, and similarly for the first sidelobe. This assumes the sensor, because of its high resolution, will not see more than one interferer at a time in its mainlobe or first sidelobe. This is a valid estimate for all but the most populated areas. Areas lost of less than 5% are considered acceptable for typical sensor operation (see CCIR Report 694-1).

Not all transmitters in the adjacent band will cause interference during an overflight. An OBRF threshold which will prevent interference can be determined for each class of transmitter; each transmitter for which the OBRF falls below the threshold for its class will cause interference. From the number of mainlobe or first sidelobe interferers a percent of area lost can be determined.

The basic assumptions used to compute the cummulative interference into the second sidelobe include a uniformly distributed population throughout the sensor's field of view and randomized pointing azimuths. Second sidelobe interference is determined from the uniform distribution, taking into account varying path lengths and associated atmospheric attenuation. By approximating high numbers of interferers with a uniform distribution, simplified geometries and some averaging techniques can be used to greatly reduce computation time over that required for models specifying exact locations and azimuths.

1.3.2 Interference from Space Stations

Two interference geometries are considered in the assessment of interference from a space station: interference into the sensor backlobe from the interferer mainlobe and interference into the sensor mainlobe and first sidelobe from energy reflected from the earth. As a worst case assumption the Earth was assumed to have a 3 dB reflection loss. Some scattering studies have indicated that reflection losses for nadir pointing antennas over land are typically greater than 12 dB at microwave frequencies.**

1.4 Interference Levels

1.4.1 Terrestrial Stations

Using the previously described models, an assessment of the interference from adjacent and subharmonic bands to remote passive microwave sensors was made for conditions representative of those over the U.S. For the case of sensor receivers which have 4 pole Butterworth characteristics, the total interference levels from terrestrial stations in adjacent and subharmonic bands is tabulated in Table 2. Each row in Table 2 lists the affected sensor frequency band, the interference threshold (from Report 694-1), the calculated level of total interference power into the sensor second sidelobe, and the percent of area lost. The percent of area lost is a function of both the area lost due to direct overflights, i.e., the area lost due to interference into the sensor mainlobe or first sidelobe, and the area lost due to interference into the sensor second sidelobe. If the calculated level of second sidelobe interference exceeds the threshold, the percent of area lost is specified as 100%; if not, the percent of area lost is just that due to direct overflights.

In the cases of allocated bands which are wider than the sensor bandwidth, for example the 51.4 to 59.0 GHz band, the 64 to 65 GHz band and the 105 to 126 GHz band, the analysis assumed the sensor was located at the low frequency end, at the high frequency end, and at the center of the allocated band.

For all bands above 10 GHz the received interference level is below the corresponding interference thresholds and the percent of area lost is below 5%.

At the lower end of the 6400 MHz band, 6425 to 6625 MHz, and at the high end, 6875 to 7075 MHz, the interference level is above threshold. Located anywhere in the range 6445 MHz to 7045 MHz interference is below threshold. Note that the percent of area lost due to direct overflights as calculated using the uniform distribution model may not be an accurate assessment of the actual area lost because the 6400 MHz band is used for ocean surface temperature measurements.

For the 4200 to 4400 MHz band the received interference power exceeds the threshold by 9.5 dB and the percent of area lost is therefore 100%. However, for a sensor bandwidth reduced from 200 MHz to 165 MHz, and centered on 4308 MHz, the interference level is below threshold and the area lost is 3.4%.

** References:

Daley, et. al.,"Sea Clutter Measurements on Four Frequencies", Naval Research Laboratory Report 6806, November 29, 1968.

Ament, et. al., "Radar Terrain Reflectors for Several Polarizations and Frequencies", Transactions of the 1959 Symposium of Radar Return, University of New Mexico, May 11-12, 1959.

Cosgriff, et. al., "Terrain Scattering Properties for Sensor System Design", Engineering Experiment Station Bulletin, Volume 29, No. 3, Ohio State University, May 1960.

Table 2. Interference Levels from Terrestrial Stations; 4 pole Receiver Characteristics

Sensor Frequency		Interference Threshold	Interference Received into Second Sidelobe	Percent of Area Lost
		dBW	dBW	%
1400-1427	MHz	-171.0	-139.3	100.0
1406-1421	"	-174.0	-162.1	100.0
4200-4400	"	-158.0	-148.5	100.0
4225-4390	"	-159.0	-159.3	3.4
6425-7075	"			
6425-6625	"	-158.0	-150.7	100.0
6445-6645	"	-158.0	-158.9	11.8
6650-6850	"	-158.0	-181.0	0.4
6845-7045	"	-158.0	-158.0	3.8
6875-7075	"	-158.0	-146.3	100.0
10.600-10.700	GHz	-156.0	-170.5	0.6
15.200-15.400	"	-160.0	-164.8	0.6
18.600-18.800	"	-152.0	-166.9	0.2
21.200-21.400	"	-160.0	-186.3	0.0
22.210-22.500	"	-155.0	-189.1	0.0
23.600-24.000	"	-157.0	-175.0	0.5
31.300-31.800	"	-156.0	-192.4	0.1
36.000-37.000	"	-146.0	-189.8	0.0
50.200-50.400	"	-157.0	-264.9	0.0
51.400-59.000	"			
51.400-51.600	"	-157.0	-336.8	0.0
55.100-55.300	"	-157.0	-336.8	0.0
58.800-59.000	"	-157.0	-336.8	0.0
64.000-65.000	"			
64.000-64.200	"	-157.0	-300.5	0.0

64.400-64.600	"	-157.0	-300.5	0.0
64.800-65.000	"	-157.0	-300.6	0.0
86.000-92.000	"	-138.0	-187.0	0.0
100.000-102.000	"	-150.0	-204.0	0.0
105.000-126.000	"			
105.000-107.000	"	-150.0	-229.7	0.0
114.500-116.500	"	-150.0	-230.5	0.0
124.000-126.000	"	-150.0	-231.2	0.0
150.000-151.000	"	-150.0	-270.1	0.0
164.000-168.000	"	-150.0	-261.6	0.0
182.000-185.000	"	-150.0	-342.2	0.0
217.000-231.000	"	-150.0	-227.9	0.0
275.000-277.000	"	-150.0	-334.3	0.0

For the 1400 to 1427 MHz band the interference level exceeds the threshold by 31.7 dB. Note that the calculated percent of area lost is valid only near land areas with a density of interferers such as that which exists in the United States. For a reduced sensor bandwidth of 15 MHz, centered at 1414 MHz, the interference level still exceeds the threshold, in this case by 11.9 dB.

The analysis of sensor operation was further refined for the 1400, 4200, and 6400 MHz bands by considering the effect of a 10 pole receiver filter. These results are shown in Table 3.

In the 1400 MHz band the reduced sensor bandwidth of 15 MHz centered on 1414 MHz results in interference, primarily subharmonic, which exceeds the threshold by 10.9 dB.

In the 4200 MHz band a sensor bandwidth of 190 MHz centered on 4305 MHz permits operation with an interference level which is below threshold and with an area lost of 1.2%.

Finally, the range of acceptable operation in the 6400 MHz band expands to 6430 to 7065 MHz with a 10 pole receiver filter.

It should be noted that in the 6400 MHz band, previous analysis (see CCIR Report 694-1) has shown that interference to passive sensors from fixed and mobile services sharing the same frequencies is significant in many areas of the world.

1.4.2 Space Stations

Calculation of the sensor interference level due to space stations in adjacent and subharmonic bands was performed for each of the sensor bands using interferer characteristics representative of all classes of space stations in the respective adjacent and subharmonic bands. A representative calculation for adjacent band fixed-satellite space stations interfering with the 18 GHz band is shown in Table 4. The total interference into the sensor backlobe and mainlobe is -199 dBW and -190 dBW respectively. Similar calculations were made for interference levels due to space stations in subharmonic bands. Calculations show that interference from space stations is below threshold for all bands considered.

1.5 Conclusions

Based on calculations using a uniform distribution model and an interferer density derived from domestic U. S. frequency lists:

For sensor operation in bands above 10 GHz, the interference level is below the threshold and the percent of area lost is less than 5% using only a 4 pole receiver filter. For these frequency bands, harmful interference from transmitters in adjacent and subharmonic bands does not constitute a problem.

In the 6400 MHz band, sensor operation with a full 200 MHz bandwidth results in interference levels below threshold for the following frequency ranges and filter types:

(a) over the frequency range of 6445 MHz to 7045 MHz using a 4 pole filter, and

(b) over the frequency range of 6430 MHz to 7065 MHz using a 10 pole filter.

In the 4200 MHz band sensor operation with a full 200 MHz bandwidth results in interference levels

Table 3. Interference Levels from Terrestrial Stations
10 pole Receiver Characteristics

Sensor Frequency	Interference Threshold	Interference Received into Second Sidelobe	Percent of Area Lost
MHz	dBW	dBW	%
1406-1421	-174.0	-163.1	100.0
4200-4400	-158.0	-152.4	100.0
4210-4400	-158.0	-160.4	1.2
6425-7075			
6425-6625	-158.0	-154.9	100.0
6430-6630	-158.0	-160.4	3.7
6650-6850	-158.0	-181.1	0.3
6865-7065	-158.0	-158.4	1.3
6875-7075	-158.0	-149.7	100.0

Table 4. Adjacent Band Interference from the Fixed-Satellite Service into the 18 GHz Sensor Band

Backlobe Contribution

Interferer EIRP (including OBRF)	26.4 dBW
Spreading Loss	-162.0 dB/m^2
Backlobe Effective Area	-63.5 dBm^2
Received Power	-199.1 dBW

Mainlobe Contribution

Interferer EIRP (including OBRF)		26.4 dBW		
Spreading Loss to Earth		-162.0 dB/m^2		
Reflection Loss		-8.0 dB		
Spreading Loss from Earth to Low Orbit		-125.0 dB/m^2		
Sensor Footprint:	Mainlobe	65.0 dBm^2	Firstlobe	79.0 dBm^2
Effective Area:	Mainlobe	13.1 dB	Firstlobe	-11.9 dBm^2
Received Power:	Mainlobe	-190.5 dBW	Firstlobe	-201.5 dBW
Total Received Power		-190.2 dBW		

above threshold. Use of guard bands can improve this result. Interference levels below threshold and areas lost of less than 5% result from the following sensor bandwidths and filter types:

(a) for a sensor bandwidth of 165MHz centered at 4308 MHz using a 4 pole filter, and

(b) for a sensor bandwidth of 190 MHz centered at 4305 MHz using a 10 pole filter.

In the 1400 MHz band calculated interference levels exceed the threshold for both of the filter types examined in this study:

(a) a 27 MHz sensor bandwidth or a 15 MHz bandwidth centered at 1414 MHz using a 4 pole filter, and

(b) a 15 MHz bandwidth centered at 1414 MHz using a 10 pole filter.

The predominant form of interference in the 1400 MHz band was subharmonic band interference.

Note that the analyses described above are considered to be the worst case situation, geographically. For much of the world's land and ocean surface areas, not within or near the United States, the observed levels of interference are likely to be less than those calculated in this report. However, the use of passive sensors at 1400 MHz over land areas having extensive numbers of transmitters in subharmonic bands, primarily from mobile communication systems, should be approached with caution because of the possibility of harmful interference.

2. Task 2 Analysis of Impact of Sensor Resolution on Interference

An initial study of the effects of relaxed sensor resolution requirements was undertaken by Dr. Brian Tunstall. This study was performed in a manner similar to CCIR Report 694, however, no final results or conclusions have been published, and the study's sole author Dr. Tunstall, no longer works for SGC. Upon review of this initial study and in light of the comprehensive computer model developed for Task 1, a slightly different approach to the Task was begun.

Calculation of interference from adjacent and subharmonic bands is now fully automated. The computer program accomplishing this, developed by Mr. Tom Tillotson under the direction of Dr. Tunstall, is easily extended to include analyses of interference from in-band interferers, i.e. shared services. To assess the effects of various sensor resolutions on interference levels simply requires changing the input data to the program. There are two ways of changing sensor resolution: specifying the desired resolution, i.e. 1km, 10km, etc., or specifying the desired antenna sizes, i.e. 0.5m, 1.0m, etc. A parametric study varying the antenna sizes has been undertaken.

In the Task 1 study a detailed examination of present day interferer populations was undertaken. Since this data is already on file it is being used in this study. A detailed examination of present day in-band interferers has now been undertaken. In a manner similar to task 1, statistics have been compiled from government and non-government frequency assignments for shared services. In some bands where no transmission is allowed we have found frequency assignments. We attempted to resolve the apparent unauthorized assignments but met with little success. Some of the assignments were typographical errors in the published listing and some assignments were for experimental or test use. Listed below are the assignments found in bands not permitting transmission. These numbers were included in the first computer analysis performed for adjacent and subharmonic band analysis.

Interferers in Bands not Allocated for Transmission
[microfiche: FCC-Feb 1983, GMF-Sept 1985]

In Band Frequency	Microfiche	Station Class	Number of Units	Bandwidth	Power	Gain	Assigned Frequency
23.6-24.0 GHz	GMF	LR	12	250MHz	50 KW	45 dB	23.6-24.47 GHz
note:	Radar for airport radar ground control.						

31.3-31.8 GHz	FCC	FX	1	10 KHz		45 dB	31.5-31.6 GHz
	FCC	MO	1	10 KHz	10 KW	0 dB	31.5 GHz
	GMF	EXP	1	10 KHz	.5 W	42 dB	31.7 GHz
note:	Test for satellite program. Located in California.						
51.4-54.25 GHz	FCC	FB/MO	6	20 KHz	25 W	0 dB	51.895 & 53.289
	GMF	EXP	20	20 MHz	.1 W	35 dB	54.0-58.0 GHz
86-92 GHz	FCC	FB2	1	20 KHz	30 W	40 dB	86.34375 GHz
105-116 GHz	GMF	EXP	2	10 KHz	20 W	40 dB	102.0-130.0 GHz
note:	For research with communications system equipment. Bell Telephone, USA.						
	FCC	MO	2	25 MHz	20 W	0 dB	102.0-130.0 GHz
note:	Bell Telephone, New Jersey.						
217-231 GHz	GMF	EXP	10	25 MHz	20 W	40 dB	185.0-230.0 GHz
note:	For research with communications system equipment. Bell Telephone, USA.						

A second search of more recent frequency assignments revealed the following assignments in bands where supposedly no transmission is allowed.

Interferers in Bands not Allocated for Transmission
[microfiche: FCC-July 1985, GMF-March 1986]

In Band Frequency	Microfiche	Station Class	Number of Units	Bandwidth	Power	Gain	Assigned Frequency
23.6-24.0 GHz	FCC	?	1	3 MHz	400 W		23.6615 GHz
note:	Van Nuys, California. Licensee: Litton Systems, Inc.						
	GMF	LR	12	250 MHz	50 KW	45 dB	23.6-24.47 GHz
note:	Radar for airport radar ground control.						
31.3-31.8 GHz	FCC	?	1	10 MHz	20 KW		31.5-52.0 GHz
note:	Coordination with TV stations. Licencee: McDonnell Douglas Radio Services Corp.						
	GMF	EXP	1	10 KHz	.5 W	42 dB	31.7 GHz
note:	Test for satellite program. Located in California.						
51.4-54.25 GHz	GMF	EXP	20	20 MHz	.1 W	35 dB	54.0-58.0 GHz
86-92 GHz	GMF	EXP	1	4 GHz	.004 W	25 dB	91.0-95.0 GHz
note:	Ground based synthetic aperture radar measurement system. Located in California.						
	FCC	FB2	1	20 KHz	30 W	40 dB	86.34375 GHz
100-102 GHz	FCC	?	3	25 MHz	20 W		92.0-101.0 GHz
note:	Bell Telephone Laboratories, New York & New Jersey.						
105-116 GHz	FCC	MO	3	25 MHz	20 W	0 dB	102.0-130.0 GHz

note:	Bell Telephone Laboratories, New York & New Jersey.					
	FCC	?	89	100 KHz	5 W	110.525 GHz
note:	Licensed under police departments, sheriff's departments, city hall, etc.					
217-231 GHz	FCC	?	3	25 MHz	20 W	185.0-230.0 GHz
note:	Bell Telephone Laboratories, New York & New Jersey.					

The source and authorization for these assignments remains unresolved.

Table 5 shows the results of an analysis similar to the adjacent band study but now including interferers sharing the sensing bands; sometimes referred to as "in-band" interferers. Two effects of the additional number of interferers can be seen. One, the percent of area lost due to direct overflights has increased slightly in bands below 10 GHz. This increase has not, however, been a factor in limiting the usefulness of the bands as the percent of area lost due to this type of interference remains below 5%. The second effect is an increase in the cummulative power into the sensor sidelobes.

The present level of refinement of our analysis shows significant changes in three areas over the previous analysis which excluded shared services. First, the 4200-4400 MHz sensing band receives more interference than previously indicated. Previously it was shown that interference from adjacent bands could be eliminated using sufficient guard bands and/or steeper filter characteristics (10 pole vs 4 pole). Now indications are that the shared services add enough interference to make sensing in this band marginal. As can be seen from the table the interference in a reduced bandwidth is 1 dB above the threshold of -158.9 dBW (4230-4385 MHz). The percent of area lost due to direct overflights is only 3.8% but since the cumulative interference is above threshold the area lost is specified as 100%. A closer look at this band may allow us to eliminate inaccuracies in the analysis such as estimates of the number of interferers, generalizing of like station classes, changes in the population since last reviewed (1 1/2 years in some cases), etc., in which case results may be more favorable. Also, although a great deal of time has been spent to make this as accurate a model as possible, a 1 dB margin of error is certainly possible. All assumptions and approximations used in the computer model have tended towards the conservative, i.e. predicting a level of interference slighlty higher than alternate assumptions or approximations.

The second area of change was an increase in interference in the 6 GHz region. As previously shown it is expected there will be interference to sensing operations at the upper and lower ends of

Table 5. Interference Levels from Terrestrial Stations

Sensor Frequency		Interference Threshold	Interference Received into Second Sidelobe	Percent of Area Lost Total (overflight)
		dBW	dBW	%
1400-1427	MHz	-171.0	-136.7	100. (100)
4200-4400	"	-158.0	-146.8	100. (6.2)
6425-6625	"	-158.0	-150.7	100. (27.7)
6525-6725	"	-158.0	-172.9	4.5
6650-6850	"	-158.0	-169.9	3.28
6675-6775	"	-158.0	-161.7	4.4
6875-7075	"	-158.0	-144.6	100. (13.5)
10.600-10.700	GHz	-156.0	-156.9	3.25
15.200-15.400	"	-160.0	-162.8	0.63
18.600-18.800	"	-152.0	-162.8	0.43
21.200-21.400	"	-160.0	-186.1	0.01
22.210-22.500	"	-155.0	-186.8	0.02
23.600-24.000	"	-157.0	-161.8	0.06
31.300-31.800	"	-156.0	-164.2	0.02
36.000-37.000	"	-146.0	-150.3	0.00
50.200-50.400	"	-157.0	-248.9	0.05
51.400-59.000	"	-157.0	-335.9	0.26
51.400-51.600	"	-157.0	-335.9	0.30
58.800-59.000	"	-157.0	-335.9	0.33
64.000-65.000	"	-157.0	-300.2	0.00
64.000-64.200	"	-157.0	-300.1	0.00
64.800-65.000	"	-157.0	-300.2	0.00
86.000-92.000	"	-138.0	-186.9	0.00
100.000-102.000	"	-150.0	-204.2	0.00
100.000-101.000	"	-150.0	-203.4	0.00
101.000-102.000	"	-150.0	-203.7	0.00
105.000-126.000	"	-150.0	-230.5	0.00
105.000-107.000	"	-150.0	-229.7	0.00
124.000-126.000	"	-150.0	-198.1	0.00
150.000-151.000	"	-150.0	-223.1	0.00
164.000-168.000	"	-150.0	-240.3	0.00
182.000-185.000	"	-150.0	-342.2	0.00
217.000-231.000	"	-150.0	-227.9	0.00
275.000-277.000	"	-150.0	-334.3	0.00

the 6425-7075 MHz sensing band, and, sensing operations will be possible near the center of the band. New indications are that there will be approximately 3.2% of area lost vs 0.4% previously indicated, and, but the cummulative interference level is still more than 10 dB below threshold. It is expected that the required guard bands at the upper and lower ends of the bands will be greater,.

The third area of change is an increase in the cummulative interference and increase in the percent of area lost at 10 GHz. This is not due to existing assignments, but, by estimating the future population of Digital Termination Systems. Our estimates are that 3,500 nodal stations and 10,000 subscriber stations could operate in the 10 GHz region without adverse effects on sensing operations. These numbers are significantly lower than estimated future populations (10,000 nodal stations and 400,000 subscribers). The compatability of DTS systems and passive sensors should be looked at in greater detail to determine if the DTS systems are being properly characterized and how compatability can be met through guard bands, higher interference thresholds, etc.

As in the previous analysis for adjacent and subharmonic bands, the 1400-1427 GHz band shows significant levels of interference from adjacent bands. Utilizing guard bands does not aid in this case since the sensing band is so narrow to begin with. In our estimate it is still infeasible to operate sensors in this band.

Above 10 GHz interference levels remain significantly below interference thresholds.

In addition to analyzing sensor bands more completely, we have carried the analysis another step in determining levels of interference utilizing various size antennas on the sensors. This is a variation on the actual task which was to study relaxed sensor resolution requirements. The driver behind studying relaxed sensor resolutions was the fact that antennas cannot be manufactured at the large antenna diameters that are required to achieve the desired sensor resolution requirements. Since the actual problem was with antenna size we decided to use diameter as a variable instead of resolution. Resolution then becomes a dependant variable of antenna diameter.

The results of the parametric study are shown in Table 6. Indicated are the antenna sizes utilized, the cummulative received power and the percent of area lost due. The study was limited to antenna diameters below 10 meters.

Three general conclusions can be drawn from the analysis. One, above 15 GHz, smaller,

Table 6. Results of Parametric Study of Changing Antenna Diameters

Sensor Frequency		Interference Threshold	Total Power Received & Percent of Area Lost at Specified Antenna Diameter					Antenna Diameter Necessary for Req'd Resolution
			.5m	1m	2m	5m	10m	
		dBW	dBW/%	dBW/%	dBW/%	dBW/%	dBW/%	m
1400-1427	MHz	-171.0	-130.8 100.	-135.7 100.	-136.5 100.	-136.7 100.	-136.7 100.	6.58
4200-4400	"	-158.0	-147.6 100.	-147.9 100.	-148.0 100.	-148.0 100.	-148.0 100.	21.61
6425-6625	"	-158.0	-150.6 100.	-150.7 100.	-150.7 100.	-150.8 100.	-150.8 100.	1.42
6525-6725	"	-158.0	-172.7 3.7	-172.9 4.7	-172.9 3.3	-172.9 4.6	-172.9 1.7	1.40
6650-6850	"	-158.0	-169.7 8.9	-169.9 4.9	-169.9 2.0	-169.9 2.7	-169.9 1.8	1.38
6675-6875	"	-158.0	-161.5 18.3	-161.6 7.0	-161.7 2.6	-161.7 6.0	-161.7 2.5	1.37
6875-7075	"	-158.0	-144.4 100.	-144.6 100.	-144.6 100.	-144.6 100.	-144.6 100.	1.33
10.600-10.700	GHz	-156.0	-156.8 100.	-156.9 40.4	-156.9 11.6	-156.9 7.1	-156.9 9.0	17.45
15.200-15.400	"	-160.0	-162.8 22.3	-162.8 7.2	-162.8 5.1	-162.8 0.9	-162.8 0.2	6.07
18.600-18.800	"	-152.0	-162.8 17.2	-162.8 4.6	-162.8 2.0	-162.8 0.4		4.97
21.200-21.400	"	-160.0	-186.1 0.1	-186.1 0.0	-186.1 0.0	-186.1 0.0		4.36
22.210-22.500	"	-155.0	-186.8 0.1	-186.8 0.2	-186.8 0.1	-186.8 0.0		4.16
23.600-24.000	"	-157.0	-161.8 1.1	-161.8 0.3	-161.8 0.1	-161.8 0.1		3.90
31.300-31.800	"	-156.0	-164.2 0.1	-164.2 0.0	-164.2 0.0	-164.2 0.2		2.95
36.000-37.000	"	-146.0	-150.3 0.2	-150.3 0.1	-150.3 0.0	-150.3 0.0		5.09
50.200-50.400	"	-157.0	-248.9 0.0	-248.9 0.0	-248.9 0.0			0.37
51.400-59.000	"	-157.0	-335.9 0.1	-335.9 0.0	-335.9 0.0			0.34
64.000-65.000	"	-157.0	-300.2 0.0	-300.2 0.0	-300.2 0.0			0.29
86.000-92.000	"	-138.0	-186.9 0.0	-186.9 0.0	-186.9 0.0			2.09
100.000-102.000	"	-150.0	-204.2 0.0	-204.2 0.0				1.84
105.000-126.000	"	-150.0	-230.5 0.0	-230.5 0.0				1.61
150.000-151.000	"	-150.0	-223.1 0.0	-223.1 0.0				1.24
164.000-168.000	"	-150.0	-240.3 0.0	-240.3 0.0				1.12
182.000-185.000	"	-150.0	-342.2 0.0	-342.2 0.0				1.01
217.000-231.000	"	-150.0	-227.9 0.0					0.83
275.000-277.000	"	-150.0	-334.3 0.0					0.67

manufacturable antennas provide suffucient gain for for the resolution requirements of passive sensing. Since these upper frequencies are for the most part not fully developed, relaxed resolution requirements, and hence smaller antennas, is feasible from an interference standpoint.

Second, decreasing the antenna size does not have a great effect on the cummulative interference since the percent of power received in the sidelobes is roughly the same as for higher gain antennas, on the order of 2%.

Third, decreasing antenna diameter and hence increasing resolution cell size has a great effect on the percent of area lost due to direct overflights. Two effects come into play as the antenna diameter decreases. First the resolution cell size increases. This causes a greater area to be lost for each case in which a direct overflight causes interference. Second, the antenna mainlobe and first sidelobe gains decrease. This causes fewer interferers to interfere in the mainlobe or first sidelobe. Primarily a lower mainlobe gain decreases the number of interferers above threshold from an adjacent band. The trade off between these two variables can be seen in the 6 GHz and 10 GHz bands where first a greater resolution cell size results in an increase in percent of area lost, then as seen in the 6 GHz band lower antenna gains results in fewer interferers in the mainlobe and first sidelobe, and then again, a larger resolution cell increases the percent of area lost. This swing back and forth from a higher to lower percentage of area lost is dependent on the types of interferers within the band and the interference margins for each station class. As the gain is lowered to alleviate each interfering station class in order of greatest interference, the percent of area lost will decrease accordingly. For bands such as the 10 GHz band where enough of the interferers are sufficiently above threshold a reasonably low antenna gain cannot be achieved. Ideally a "best resolution" can be chosen where the combination of area lost, sensor resolution and cummulative power result in the optimal of the use of the band; this is of course predicated on the fact that there will be interference in the band. Ideally we would like there to be no interference.

Conclusions

For 18 GHz and above, sensor resolution requirements can be relaxed to the point where a 1 meter antenna can be used at 18 GHz, and as small as a 0.5 meter antenna for bands above 18 GHz. This statement is based soley on an assessment of interference. Some consideration needs to be given to the actual usefulness of the resultant resolution, i.e. can enough detailed information be obtained at a reduced resolution to make sensing worthwhile?

Taking a closer look at the bands below 18 GHz we can see that the 1400-1427 GHz band has interference well above threshold, even for a resolution greater than that required for operation in this band. We can not determine any method at this time that will alleviate interference in this band.

Significant levels of interference exist in the 4200-4400 GHz band. The percent of area lost, 100%, is not indicative of direct overflight interference, but, of the cummulative interference being above threshold. The level of interference utilizing smaller than ideal antennas is the same as for utilizing the required 21.6 meter diameter antenna. This is because the second and far sidelobes still accumulate approximately 2% of the total interference power. Suitable guard bands or other methods of alleviating interference have not yet been determined. If, at the required antenna diameter of 21.6 meters, we can determine a way to alleviate interference, it is expected that operation in this band would also be possible utilizing a smaller antenna, on the order of 2 meters.

As shown in the previous adjacent band study there are significant levels of interference to sensing operations performed at the extremes of the 6425-7075 MHz band. Interference levels at the lower end of the band, 6425-6625 MHz, are 8 dB above the interference threshold and at the upper end, 6875-7075 MHz, are 14 dB above threshold. Sensing can be performed in the center of the band. The interference experienced in the 6650-6850 MHz band is 11 dB below the interference threshold. The resolution required in this band is only 20 km, and thus only a 1.38 meter diameter antenna would be required. We have determined that an antenna as small as 1 meter can be used without exceeding 5% area lost. Additional antenna sizes are shown in the table and indicate that higher resolutions than required can be obtained without adverse interference.

In the 10.6-10.7 GHz sensing band it does not appear feasible to utilize relaxed sensor resoltuions. This is primarily due to the Digital Temination Systems planned for this band. Sensing could be accomplished for some years to come until DTS systems achieve greater use. As discussed earlier, the number of DTS systems used in this analysis was much less than predicted future use. We chose to present the data this way in order to indicate the level, or population, at which interference could be expected. The parametric analysis utilizing reduced sensor resolution was carried out using the reduced number of DTS systems indicated earlier in this report. The results show that not only is the number of DTS systems limited, but the percent of area lost is also greater than 5%; 9% utilizing a 10 meter antenna. It appears that relaxing the sensor resolution requirements is not viable in this band. Further analysis should be made to determine whether some operational restrictions can be used to achieve compatability between DTS systems and passive sensors.

In the 15.2-15.4 GHz sensing band a 6.1 meter antenna is required to achieve the desired resolution. Our study indicates that an antenna as small as 2 meters could be used for sensing with only 5.1% area loss and a cummulative interference level 2.8 dB below the interference threshold. If a larger area lost can be tolerated then antenna diameters as small as 0.5 meter can be used. At 0.5 meters the cummulative interference is still 2.8 dB below threshold, except the area lost is 22.3%. Sensing at this reduced resolution may be possible if it is limited to unpopulated areas where a direct overflight of an interferer is less likely.

3. Task 5- Develop Performance Criteria, Interference Criteria, Sharing Criteria, and Coordination Criteria.

The criteria for sharing and coordination between the Earth Exploration Satellite service and other radio services has not been fully developed at this time. This purpose of this paper is to develop a plan showing how the necessary criteria might be developed.

Some criteria does exist in the form of general restrictions, protection criteria and coordination procedures for space and terrestrial services sharing the same bands. These criteria are as follows:

1) Power Flux Density Limits as outlined in Article 28 of the Radio Regulations. This Article does not pertain directly to the protection of EES services, but, does impose limitations on the power that a transmitting spacecraft can employ and will therefore have an effect on link performance and receiving system parameters. Limiting spacecraft transmit power will require more sensitive receiving systems that may in turn be more susceptible to interference.

2) Equivalent Isotropically Radiated Power Limits and antenna pointing limits as outlined in Article 27, RR. This Article was intended to protect systems operating in the GSO from fixed and mobile services but has a further effect on low orbit satellites in that a maximum e.i.r.p. of +55 dBW is specified for stations pointing in any direction. This level is still sufficiently high to cause interference to low orbit sensors or telecommunication links under a variety of conditions, but, provides some regulation.

3) Coordination areas determined per Appendix 28, RR, for coordination between Earth stations and terrestrial services. Coordination contours are an effective means of establishing the need for coordination. At present the only EES entry in Appendix 28 is in the 8025-8400 MHz. This band and the 65-66 GHz band are the only primary allocations for EES telemetry. Entries in Appendix 28 for EES bands having Secondary status may be valuable for coordination between services of equal status and for consideration by primary services.

4) Appendix 29, RR, delta T/T calculations for coordination between satellite networks utilizing the geoststionary orbit. Generally earth exploration satellites will be low orbit satellites and will not be subject to the criteria set forth in Appendix 29. Also, low orbit

satellites are secondary to satellite systems utilizing the GSO. EES are, however, utilizing the GSO for data relay (Earth Resource Budget Satellite now operational). In this case the actual service will be intersatellite or fixed-satellite supporting earth exploration and will have the same status as other data relay services utilizing the GSO. In general this Appendix will not apply to the EES service.

5) CCIR Recommendation 514 which specifies maximum received power densities from shared services. This recommendation is a broad statement of the performance and protection criteria required for earth exploration. It does not address specific EES telemetry bands in terms of sharing criteria, or adjustments to the protection criteria set forth. It sets forth baseline requirements which can be studied in more detail for specific telemetry bands.

Indicated in tables 1,2, and 3 are frequency bands allocated for EES telecommunications, EES passive sensing and EES active sensing. Shown in the tables is the allocation status, shared services and in some cases applicable criteria.

Criteria that actually specifies maximum permissible interference power at system inputs, such as numbers 3, 4, and 5 above, has been developed using system noise power as a reference. Number 4 above, delta T/T calculations, actually references interference to the equivalent noise temperature. Number 5, CCIR Recommendation 514, has a permissible interference level based on a 1 dB degradation in signal to noise which corresponds to an order of magnitude increase in the bit error rate. Knowing the system noise level and bandwidth, permissible interference can be specified as an absolute power or power/bandwidth. The level of permissible interference specified in Rec. 514 is used in Appendix 28 to determine coordination distances.

Determining suitable criteria for EES bands depends on the use of the band and the shared services. For example the criteria developed for an EES passive sensing band will be developed in a manner different than for a telemetry band. In either case the resultant criteria will be related to, and can be referenced from the system noise power or equivalent system noise temperature.

A general procedure can be followed to quantize the required protection criteria. This is as follows:

1) *Determine system characteristics.* This includes system noise temperature, desired BER,

S/N or C/N, antenna gain, desired signal PFD, processing gains, reference bandwidth, etc.

2) *Determine the degradation in C/N or S/N that can be tolerated.* This is usually based on the highest BER that can be tolerated, or, on signal aquistion thresholds.

3) *Calculate the interference power that results in the specified S/N degradation.* This is the power at the input of the receiving system from the output of the receiving antenna.

4) *Determine protection criteria based on the interference power.* This can be the actual level of interference power that causes the S/N degradation, or can be expressed as a percentage of noise power or noise temperature.

5) *Determine sharing criteria based on protection criteria.* This usually requires a knowledge of interferer populations or number of interference entries. Sharing criteria is then the maximum allowable interference from an individual interferer such that the cummulative interference does not exceed the protection criteria.

Developing Criteria for Telecommunication Bands

In telecommunication bands, interference and sharing criteria are needed to maintain data integrity whether the data is telemetry, telecommand, playback of stored scientific data, or real time scientific data. In an effort to gather information on EES telecommunication requirements we have looked at another service, the Space Research Satellite (SRS) service which has virtually identical telecommunication requirements. Some standards are presently being proposed for the Space Research Service (SRS) in CCIR SG2 document 2/1029-E, Protection Criteria Relating to Near-Earth Space Research Systems The very same approach outlined in this document can be applied to the EES.

The basis for developing protection criteria for receiving Earth stations in the referenced report is that a 1 dB degradation in the link threshold performance will result in harmful interference, and that this corresponds to an interference to noise (I/N) of -6 dB. Synonymous with link threshold performance in the last statement is signal to noise ratio. According to CCIR Report 544 where empirical data was taken on a narrowband phase-locked loop, a 1 dB degradation of S/N in the loop occurred when the I/N was approximately -3 dB. The actual I/N at threshold depends on the criteria selected for determining the threshold, i.e. loss of lock or rate of skipped cycles. Report 544 goes on to state that 1 dB degradation in the loop S/N for a typical operating level of 6 dB was enough to cause loss of lock.

A second justification for using a 1 dB degradation in S/N as the protection criteria is that at the typical BER rates used for space telecommunications, one error in 10^5 to 10^6 bits prior to error correction, this amount of degradation results in an order of magnitude reduction in the BER.

As put forth in CCIR Recommendation 514, a typical Earth station receiver may have a noise temperature of 100 K (-148 dBW/MHz), and utilizing a 1 dB degradation in S/N as the protection criteria, the total interference power in any 1 MHz band should not exceed -154 dBW/MHz, and given that cosmic noise will increase the system operating noise temperature 20 dB per decreasing frequency decade so shall the total permissible interference power increase.

For a receiving space station operating at approximately 600 K (-171 dBW/KHz) a 1 dB S/N degradation would occur at I/N levels of -177 dBW/KHz. CCIR Recommendation 514 specifies that techniques are available for protection against interference 10 dB above the noise level. This is usually done by increasing ES transmitter power and means that interference as high as -161 dBW/KHz can be tolerated. A more conservative approach, especially for use during orbit transfer or on manned missions would be to utilize a maximum interference level of -177 dBW/KHz as the protection criteria used in coordination procedures.

Developing Criteria for EES Passive Sensing Bands

Protection criteria has been established for passive sensing bands in CCIR Report 694 as 20% of the minimum discernable power. CCIR Report 693 establishes the minimum discernable power change to provide useful passive sensing. The criteria established from these two reports appears in Table 2. The first CCIR documents on passive sensing published in the early 1970's set forth the 20% of minimum discernable interference power criteria, a choice that is not fully explained in available literature.

Extensive analysis has been performed on all passive sensing bands to determine levels of interference that can be expected when operating over an industrialized area such as the U.S. The analysis can be found in two reports: Interference to Remote Passive Microwave Sensors from Adjacent and Subharmonic Bands, April 1985, NASA Contract NASW - 3973, and Analysis of

Interference to Remote Passive Microwave Sensors, July 1986, NASA Contract NASW - 3973.

Sharing criteria in sensing bands where interference exists can be determined from the interference margin in those bands. For example utilizing present interferer statistics interference to sensors operating in the 10.6-10.7 GHz sensing band will be below threshold. However, within this band and in the lower adjacent band there are plans for Digital Termination Systems.

According to present estimates there are expected to be 10,000 nodal stations and 400,000 subscriber stations. An analysis was made to determine how many interferers of this station class could be in operation before a low orbit sensor received interference above threshold. It was determined that at a point where 3,500 nodal and 10,000 subscriber stations were in service, interference to the passive sensor would be above threshold (see NASW - 3973, July 1986, report referenced above, section 5.3).

Considering the estimates for future use of this service, an average reduction in total eirp towards the sensor of 4.6 dB for nodal and 16.0 dB for subscriber stations would be required for interference free sharing. This reduction can be realized through increased mainlobe gain and decreased transmitter power, decreased sidelobe levels, and decreased numbers of transmitters. The threshold for interference in this band is -156 dBW total power, therefore sharing criteria between the DTS station class and passive sensors should be established as -156 -4.6 = -160.6 dBW interference from individual nodal stations and -156 -16 = -172 dBW interference from individual subscriber stations.

Developing Criteria for EES Active Sensing Bands

An analysis of sharing between spaceborn active microwave sensors and terrestrial radar has been performed in CCIR Report 695-1. The report studied state of the art spaceborn synthetic aperture radar and terrestrial pulsed type radiolocation radar. Conclusions drawn from the report are: that in low gain modes no interference is expected from terrestrial stations, in high gain modes perceptible interference may occur and would be similar to that encountered by currently operating airborne mapping radars, and interference free SAR operation could be achieved through the use of limited receive power levels in the SAR at the cost of reduced dynamic range.

Based on the processing gain of the desired signal and that of the noise it was determined in Report 695-1 that the maximum undesired signal is -94 dBW. An analysis of the sidelobe to sidelobe coupling from terrestrial to spaceborn radars indicates that the received power from systems outlined in Report 695-1 will be on the order of -112 dBW. This leaves an interference margin of 18 dB. For interference to occur during sidelobe to sidelobe coupling at least 63 interfering stations would have to be coherently transmitting; not a likely scenario. There will however be interference when the radar is on the horizon or overhead of the interfering stations and the terrestrial station sweeps past the satellite. Interference in such cases cannot be reasonably avoided because of the nature of the systems and are analyzed in the Report 695-1. The argument for interference free operation in this case is that the terrestrial station will not likely sweep past the satellite on every pass, therefore subsequent passes will result in uncontaminated images.

According to recent FCC and Government frequency lists there are some 4400 terrestrial radiolocation / radiodetermination systems presently operating near 1.2 GHz, only a fraction of which will be operating in the sensors passband. To establish sharing criteria would require a statistical analysis to determine how often a sufficient number of emitters would be coherently transmitting towards the radar during any given pass and the maximum number of passes to obtain an error free image would have to be determined.

Table 1. Frequency Allocations for the Earth Exploration Satellite Service

Frequency [GHz]	Link	Status	Comments and Sharing*	Applicable Criteria**
.401- .403	E-S	Secondary	Shared with: METEOROLOGICAL AIDS; SPACE OPERATION; Meteorological Satellite; Fixed & Mobile.	Appendix 29
.460- .470	S-E	Secondary	Subject to not causing harmful interference (671). Shared with: FIXED & MOBILE; Meteorological Satellite (S-E); Maritime Mobile (equipment to conform with app. 20).	Recommendation 514 Appendix 29
1.525- 1.535		Secondary	Shared with: SPACE OPERATION (S-E); FIXED & MOBILE; MARITIME MOBILE (S-E) (effective from Jan. 1990).	Article 27 (2502) Article 28 (2557) Appendix 29
1.69- 1.71	S-E	Secondary	Subject to not causing harmful interference (671). Shared with: METEOROLOGICAL AIDS; METEOROLOGICAL SATELLITE (S-E); FIXED & MOBILE.	Recommendation 514 Article 27 (2502) Article 28 (2553, 2557) Appendix 29
2.025- 2.11	E-S S-S	Secondary	Subject to interference agreement (747). Shared with: FIXED & MOBILE; (E-S)/(S-S) links of the Space Research and Space Operation Service (747).	Article 27 (2502) Appendix 29
2.2- 2.29	S-E S-S	Secondary	Subject to interference agreement (750). Shared with: FIXED & MOBILE; (S-E)/(S-S) links of the Space Research and Space Operation Service (750).	Recommendation 514 Article 27 (2502) Appendix 29
8.025- 8.175	S-E	Secondary Primary	in Regions 1 & 3. in Region 2. Shared with: FIXED & MOBILE; FIXED SATELLITE (E-S).	Recommendation 514 Article 27 (2502, 2505, 2507) Article 28 (2570) Appendix 28 Appendix 29
8.175- 8.215	S-E	Secondary Primary	in Regions 1 & 3. in Region 2. Shared with: FIXED & MOBILE; METEOROLOGICAL SATELLITE (E-S); FIXED SATELLITE.	Recommendation 514 Article 27 (2502, 2505, 2507) Article 28 (2570) Appendix 28 Appendix 29
8.215- 8.4	S-E	Secondary Primary	in Regions 1 & 3. in Region 2. Shared with: FIXED & MOBILE; FIXED SATELLITE (E-S).	Recommendation 514 Article 27 (2502, 2505, 2507) Article 28 (2570) Appendix 28

				Appendix 29
# 22.55- 23.		Primary	Inter-satellite link. Shared with: FIXED & MOBILE; BROADCASTING SATELLITE.	Appendix 29
# 23.0- 23.55		Primary	Inter-satellite link. Shared with: FIXED & MOBILE.	
25.25- 27.5	S-S	Secondary	Shared with: FIXED & MOBILE; Standard Frequency and Time Signal Satellite (E-S); FIXED SATELLITE in the 27-27.5 range.	Article 27 (2505, 2508) Appendix 29
29.95- 30.	S-S	Secondary	for telemetry, tracking and control purposes (882). Shared with: FIXED SATELLITE (E-S); Mobile Satellite (E-S); Fixed & Mobile.	Appendix 29
65.- 66.		Primary	No direction given. Shared with: SPACE RESEARCH; Fixed & Mobile.	Appendix 29

* Primary services are in CAPITALS, secondary services are in regular print. Footnotes are parenthesized.

** Parenthesized numbers indicated paragraph number of specified article.

\# The Earth Exploration Satellite Service is not allocated in these bands, but the Inter-Satellite Service may imply links with EES systems provided water vapor sensing is not carried out on the spacecraft near these bands.

Table 2. Allocations for Passive Sensors

Frequency [GHz]	Status	Comments and Sharing*	Interference Threshold [dBW]
1.400-1.427	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-171.0
4.200-4.400	Secondary	Footnote allocation. Shared with: AERONAUTICAL RADIONAVIGATION.	-158.0
6.425-7.075	Secondary	Footnote allocation. Shared with: FIXED, MOBILE FIXED-SATELLITE (Earth to space)	-158.0
10.600-10.700	Primary	Shared with: FIXED, MOBILE, RADIO ASTRONOMY, SPACE RESEARCH, Radiolocation.	-156.0
15.200-15.400	Secondary	15.2-12.35 GHz Shared with: FIXED, MOBILE, Space Research	-160.0
	Primary	15.35-15.4 GHz. Shared with: SPACE RESEARCH (passive), RADIO ASTRONOMY.	
18.600-18.800	Secondary	Regions 1 & 3 Shared with: FIXED, MOBILE,	-152.0

		FIXED-SATELLITE (space to Earth), Space Research (passive).	
	Primary	Region 2 Shared with: FIXED, MOBILE, FIXED-SATELLITE (space to Earth), SPACE RESEARCH (passive).	
21.200-21.400	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-160.0
22.210-22.500	Primary	Shared with: FIXED, MOBILE, RADIO ASTRONOMY, SPACE RESEARCH (passive).	-155.0
23.600-24.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-157.0
31.300-31.800	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive) 31.5-31.8 GHz in Regions 1 & 3- Fixed, Mobile.	-156.0
36.000-37.000	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-146.0
50.200-50.400	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-157.0
51.400-59.000	Primary	Shared with: SPACE RESEARCH (passive) 54.25-58.2- GHz FIXED, MOBILE, INTER-SATELLITE.	-157.0
64.000-65.000	Primary	Shared with: SPACE RESEARCH (passive).	-157.0
86.000-92.000	Primary	Shared with: SPACE RESEARCH (passive), RADIO ASTRONOMY.	-138.0
100.000-102.000	Primary	Shared with: FIXED, MOBILE, SPACE RESEARCH (passive).	-150.0
105.000-126.000	Primary	Shared with: 105-116 GHz- RADIO ASTRONOMY, SPACE RESEARCH (passive), 116-126 GHz- FIXED, MOBILE, INTER-SATELLITE, SPACE RESEARCH (passive).	-150.0
150.000-151.000	Primary	Shared with: FIXED, MOBILE, INTER-SATELLITE, SPACE RESEARCH (passive), FIXED-SATELLITE (space to Earth).	-150.0
164.000-168.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-150.0
182.000-185.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-150.0

217.000-231.000	Primary	Shared with: RADIO ASTRONOMY, SPACE RESEARCH (passive).	-150.0
275.000-277.00		Not allocated.	-150.0

Table 3. Allocations for Active Microwave Sensors

Frequency [GHz]	Status	Comments and Sharing*
1.215 - 1.3	Secondary	RADIOLOCATION, RADIONAVIGATION-SATELLITE Amateur
3.1 - 3.3	Secondary	RADIOLOCATION
5.25 - 5.35	Secondary	RADIOLOCATION, Space Research
8.55 - 8.65	Secondary	RADIOLOCATION
9.5 - 9.8	Secondary	RADIOLOCATION, RADIONAVIGATION
13.4 - 14.0	Secondary	RADIOLOCATION, Standard Frequency and Time Signal Satellite (E-S), Space Research
17.2 - 17.3	Secondary	RADIOLOCATION, Space Research (active)
24.05 - 24.25	Secondary	RADIOLOCATION, Amateur
33.5 - 35.6	Primary	RADIOLOCATION, Space Research
78. - 79.	Primary	RADIOLOCATION, Amateur, Amateur Satellite

4. Task 6- Spectrum Engineering for NASA Microwave Sensor Projects

In the time frame between the interim report and the present, the only additional work that has been requested has been an analysis of the use of active microwave sensors in search and rescue opoerations. A system has been proposed whereby active microwave sensors (radar) in low orbit may be used in Search and Rescue (SAR) operations to detect distress signals. Distress signals will be in the form of abnormally high reflectivity due to the presence of a passive reflector. If a sufficient resolution can be obtained distress signals can be indicated by specific reflector arrangements.

Calculations were made to determine the feasibility of utilizing the active sensor in SAR. Based on a simple geometry utilizing a low orbit active sensor with a 60 degree depression angle, the required passive reflector sizes, sensor antenna size and gain, and resolution cell size have been determined.

Graph 1 shows the required gain to achieve the desired resolution from a 500 km orbit altitude. This reflects the required antenna size for a physically scanning system, i.e. not a synthetic aperture. Graph 2 shows the required antenna diameter to provide 1 km resolution. The frequencies in graph 2 are presently allocated active sensing bands. Table 1 below indicates the bands allocated below 100 GHz. It is expected that the lower bands would be more suitable for the purpose of SAR since they will be less effected by adverse weather.

Table 1. Allocations for Active Microwave Sensors

Frequency Band (GHz)	Wavelength (cm)
1.215 - 1.3	24.69 - 23.08
3.1 - 3.3	9.68 - 9.09
5.25 - 5.35	5.71 - 5.61
8.55 - 8.65	3.51 - 3.47
9.5 - 9.8	3.16 - 3.06
13.4 - 14.0	2.24 - 2.14
17.2 - 17.3	1.74 - 1.73
24.05 - 24.25	1.25 - 1.24
33.5 - 35.6	0.90 - 0.84
78. - 79.	0.38

Graph 3 shows the required passive reflector equivalent flat plate area to achieve an echo 15% above normal backscatter. This is plotted against the land scattering coefficient. Typical scattering coefficients will be between -30 and -5 dB for most land areas when sensing from 10 to 40 GHz. This was determined from data available in the "Manual of Remote Sensing", Vol 1., American Society of Photogrammetry, and Figure 3 of CCIR Report 850. As can be seen by graph 3 a relatively small (<1 meter^2) effective area is required to detect a 15% greater backscatter over most land areas when utilizing a 1 kilometer resolution. Graphs 4 and 5 show the edge dimension of a triangular and square trihedral reflector required to produce an echo at15% above normal backscatter. Graph 6 shows the required reflector effective area vs resolution.

Discussion of Analysis

Certain general observations can be made from the calculations used to produce the graphs in this report. They are:

1. To be effective for search and rescue resolution must be kept to within a few kilometers. If the resolution was worse than a few kilometers it will be defeating its usefulness for locating distress sites. In addition a larger resolution will require a larger target in order to be detected; this is shown by graph 6.

2. Relatively high antenna gains are required to produce the desired resolutions when a scanning system, i.e. not synthetic aperture, is used to detect distress signals. This is apparent from graph 1 where it is shown that at least 54 dBi gain is required to produce a 2 km resolution from an orbit altitude of 300 km.

3. The antenna diameters necessary to produce the required gain, as shown in graph 2, may prohibit the use of a scanning system in the micowave region for SAR. The nature of the service and the high resolution that is required will necessitate the use of a low orbit sensor able to scan with a swath width many times greater than its resolution. The ability to rotate or scan with such a large antenna (greater than 3 meters in diameter) on a spacecraft is not presently feasible. There may, however be a way to utilize a modified parabola or circular reflector and a rotating antenna feed in a manner similar to the TDRS single access antennas to provide a scanning beam. Another alternative may be to use a zero momentum spacecraft where the large counter-rotating body of the spacecraft can be used to offset the momentum of the rotating antenna. The intent of this report is to address the possibility of using a simple scanning system, however, another alternative is the use of synthetic aperture radar.

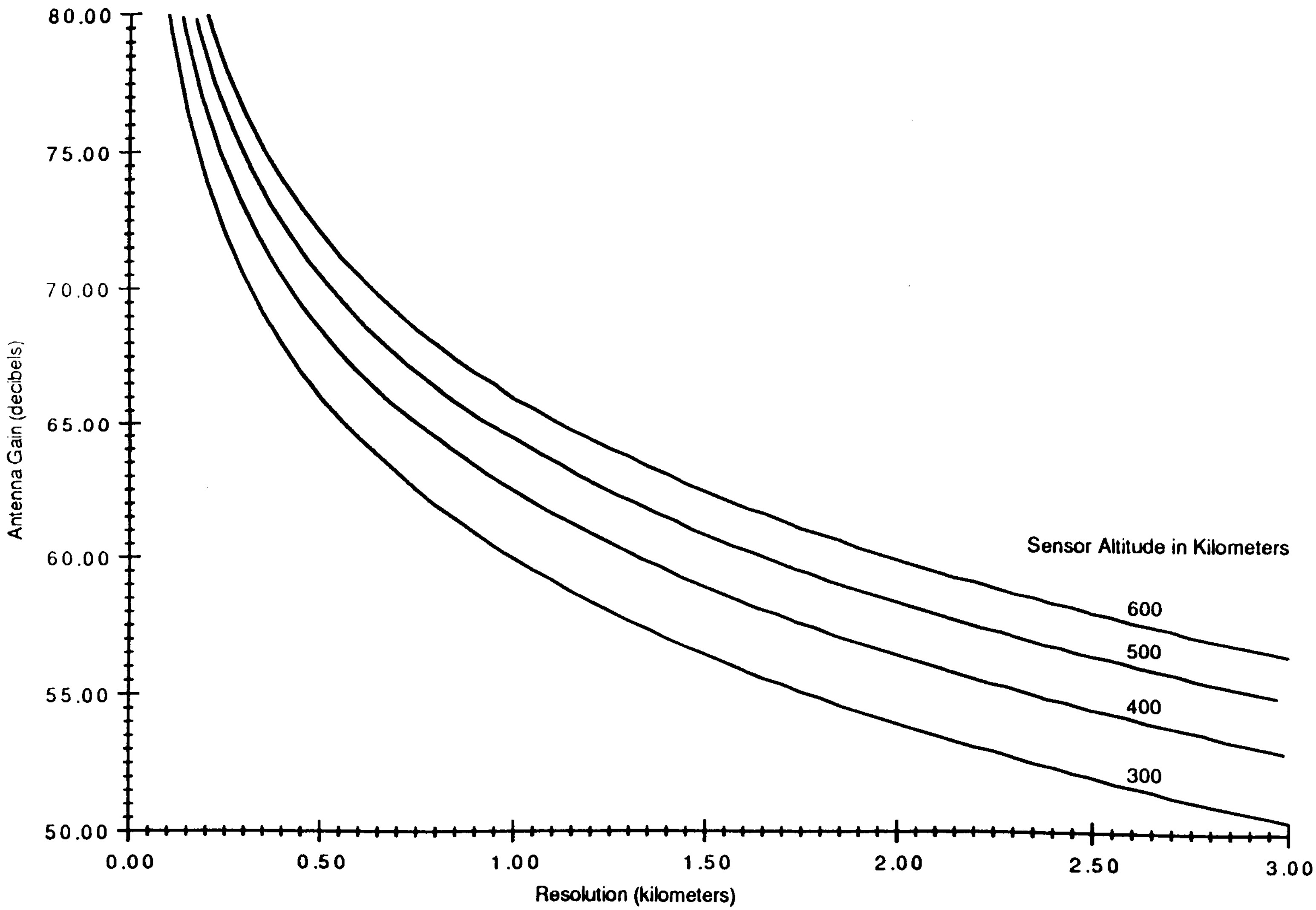
4. Irrespective of the sensor altitude, a resolution less than 3 kilometers can be obtained utilizing a reflector with an effective area less than 2 square meters, the equivalent of a trihedral reflector with edge dimensions less than 2 meters. It has been shown in an experiment by NASA outlined in the publication "A Global Search and Rescue Concept Using Synthetic aperture Radar and Passive User Targets", NASA TN D-8172, that aluminized mylar can be supported by a light framework to produce a viable reflector target. Such a target can be be stowed in a compact form and set up in times of distress. This experiment was conducted using an aircraft flown at a 1.9 kilometer altitude utilizing synthetic aperture radar, and plans for a space shuttle test were being formulated.

5. Without the use of synthetic aperture radar resolution will be measured in kilometers. This will not allow the grouping of distress targets in known geometric patterns for better detection and identification of actual distress. This is a key issue in the synthetic aperture radar experiment. False indications of distress from a system that has a resolution on the order of kilometers may come from almost any metallic object such as ships, drilling platforms, airplanes at sea, or cars, trucks, buildings, or towers on land. Such a preponderance of false indications would render the system worthless.

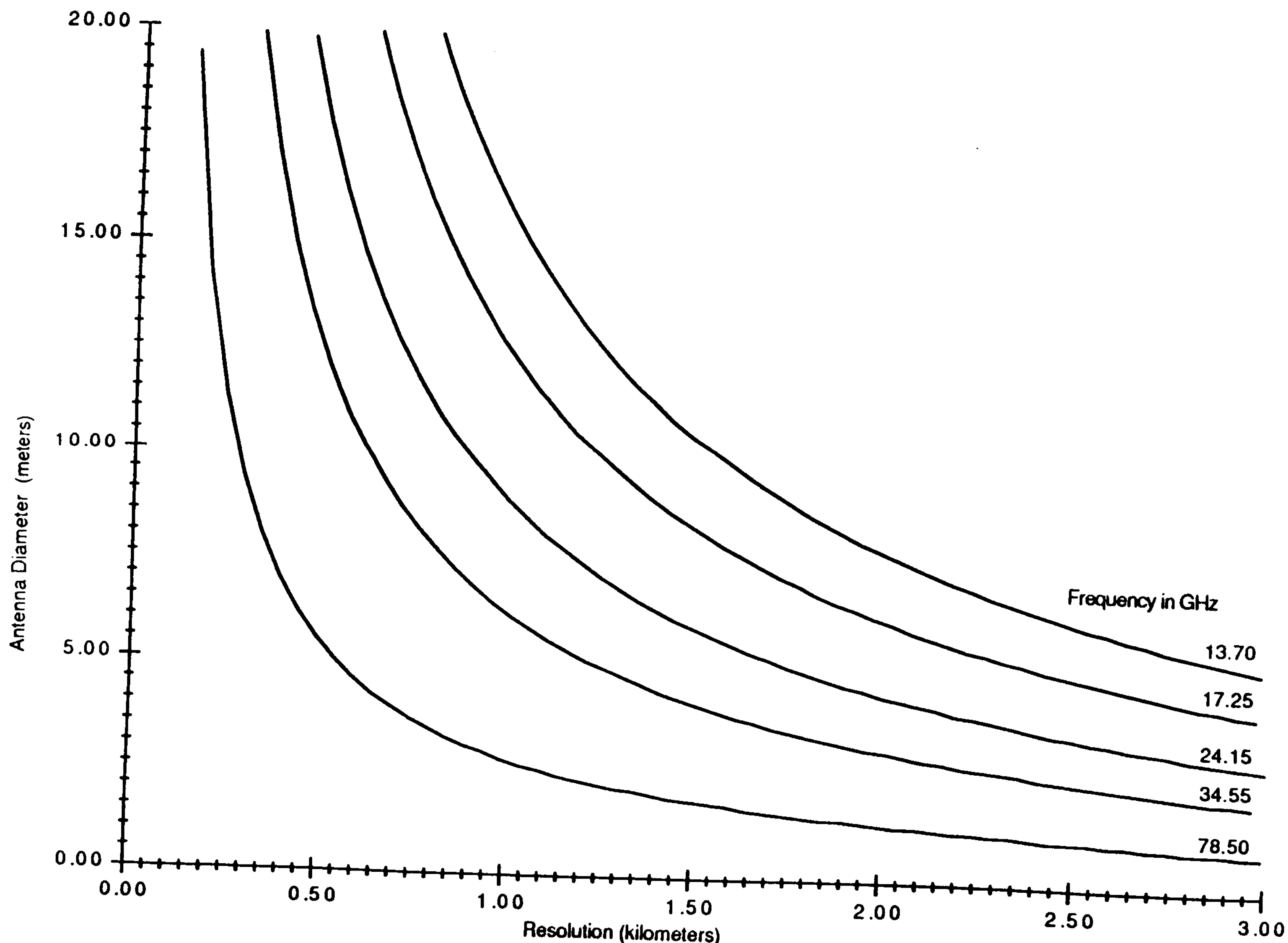
6. A low orbiting system providing resolution in the kilometer range may prove useful for narrowing the search area for terrestrial SAR craft. Instead of searching wide areas of ocean or land, searches can be confined to within an area the size of the sensor resolution. Radar on terrestrial SAR craft can then be used within these areas to pin-point distress sites.

Conclusions

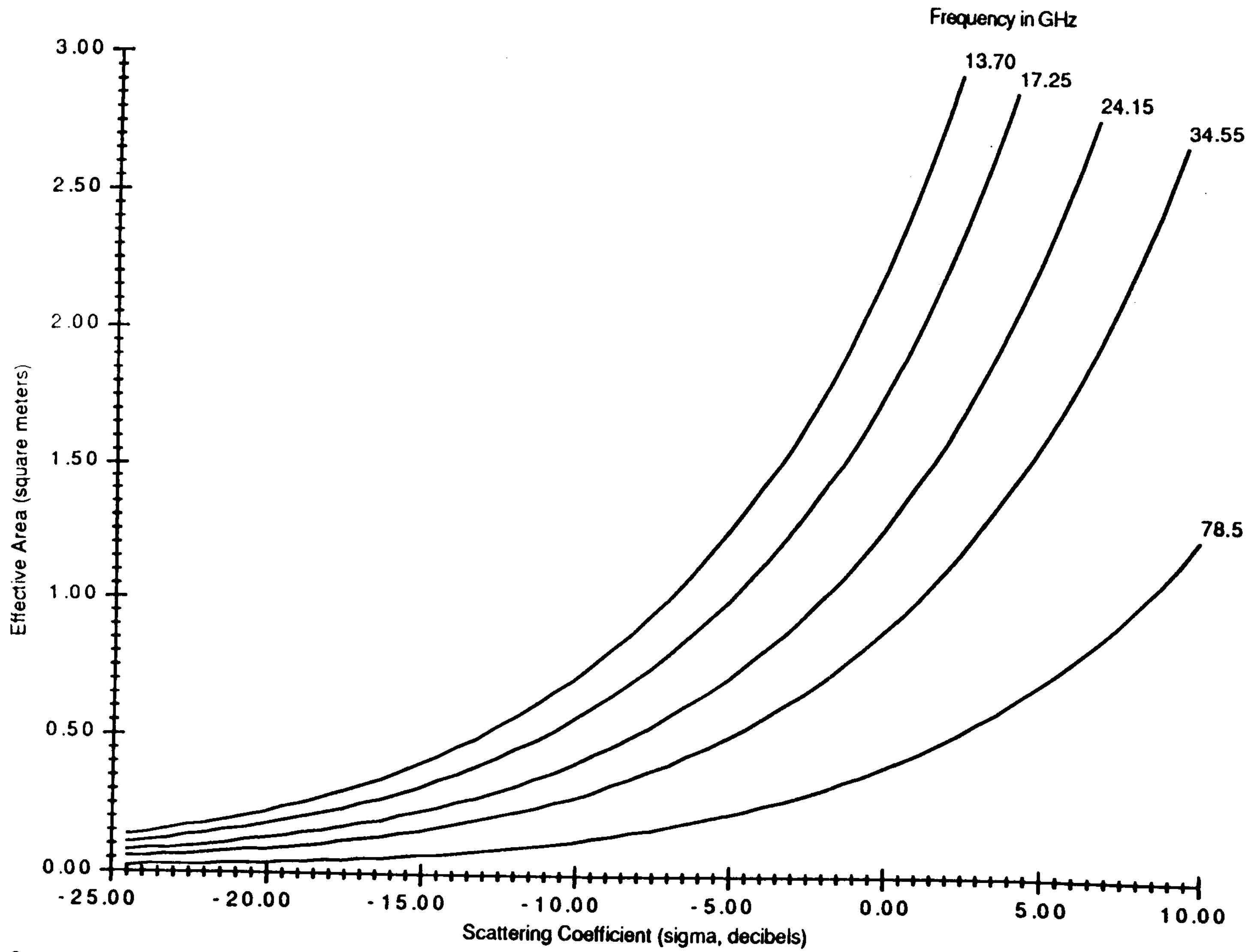
At least three points can be identified which will require significant efforts to produce a viable search and rescue system. One, sufficient antenna gain will be required to achieve adequate resolution on the order of one to three kilometers. Two, a means of scanning will have to be devised, whether by rotating the entire antenna or only the antenna feed. And three, a means of positively identifying distress signals from false echos will have to be devised. Distress signals will most likely come from remote areas on land or at sea. Objects producing high reflectivity will probably be manmade and will for the most part be located near populated areas, areas where a global SAR system will not be required. Therefore, prior knowledge of an area being sensed, and an indication of potential distress, i.e. overdue communications, distress calls, etc., will aid in reducing false distress signals and speed location detection. Aid in locating a known distress situation may be sufficient to warrant development of such a system, however, some new procedure or technique will still have to be developed in order to produce a system that can provide the initial detection of distress.



Graph 1. Required Antenna Gain vs Resolution for Various Altitudes, 60 Degree Depression Angle

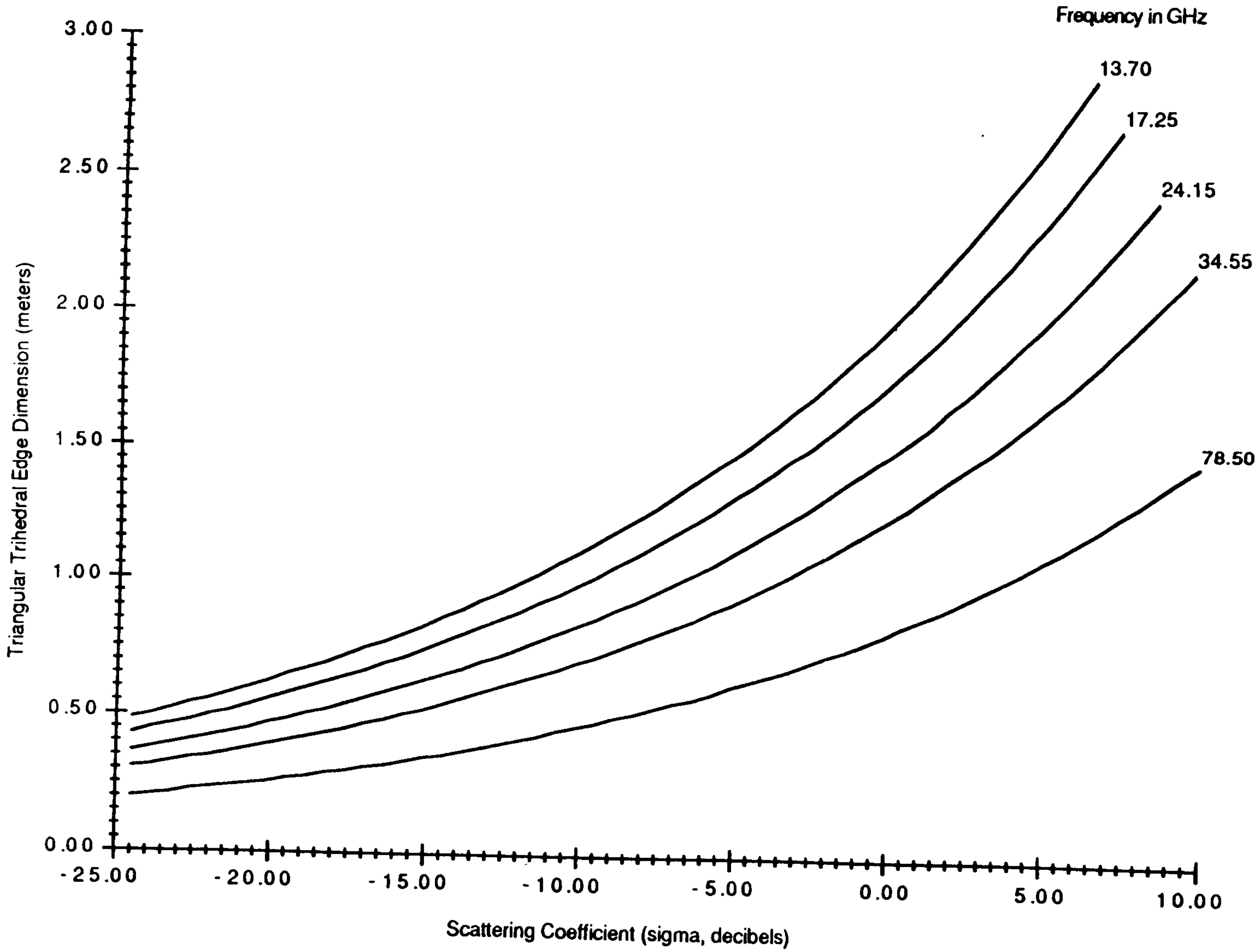


Graph 2. Required Antenna Diameter vs Resolution for Various Frequencies 60 Degree Depression Angle, 500 Kilometer Orbit Altitude

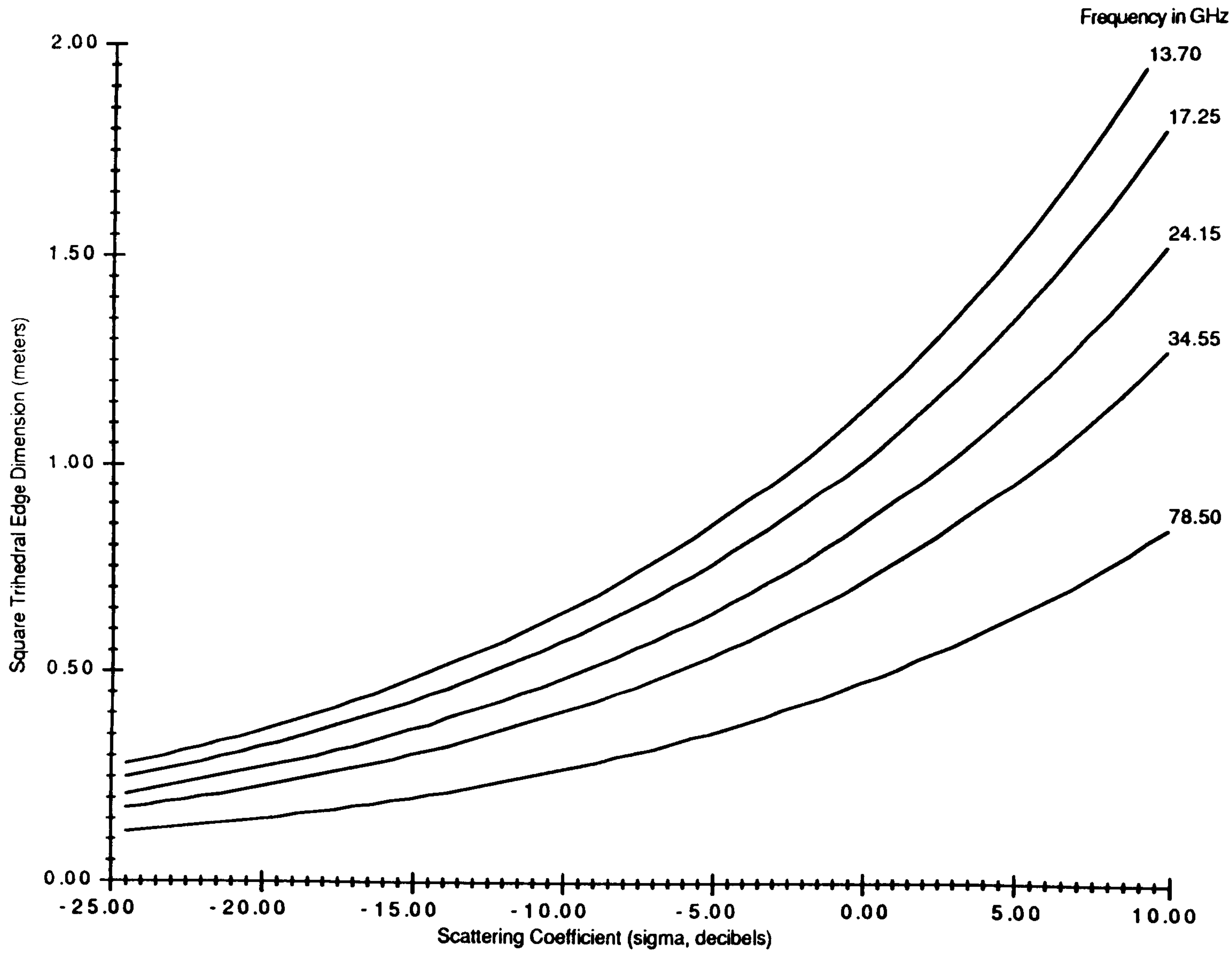


Graph 3. Required Passive Reflector Effective Area vs Scattering Coefficient (sigma) for Various Frequencies

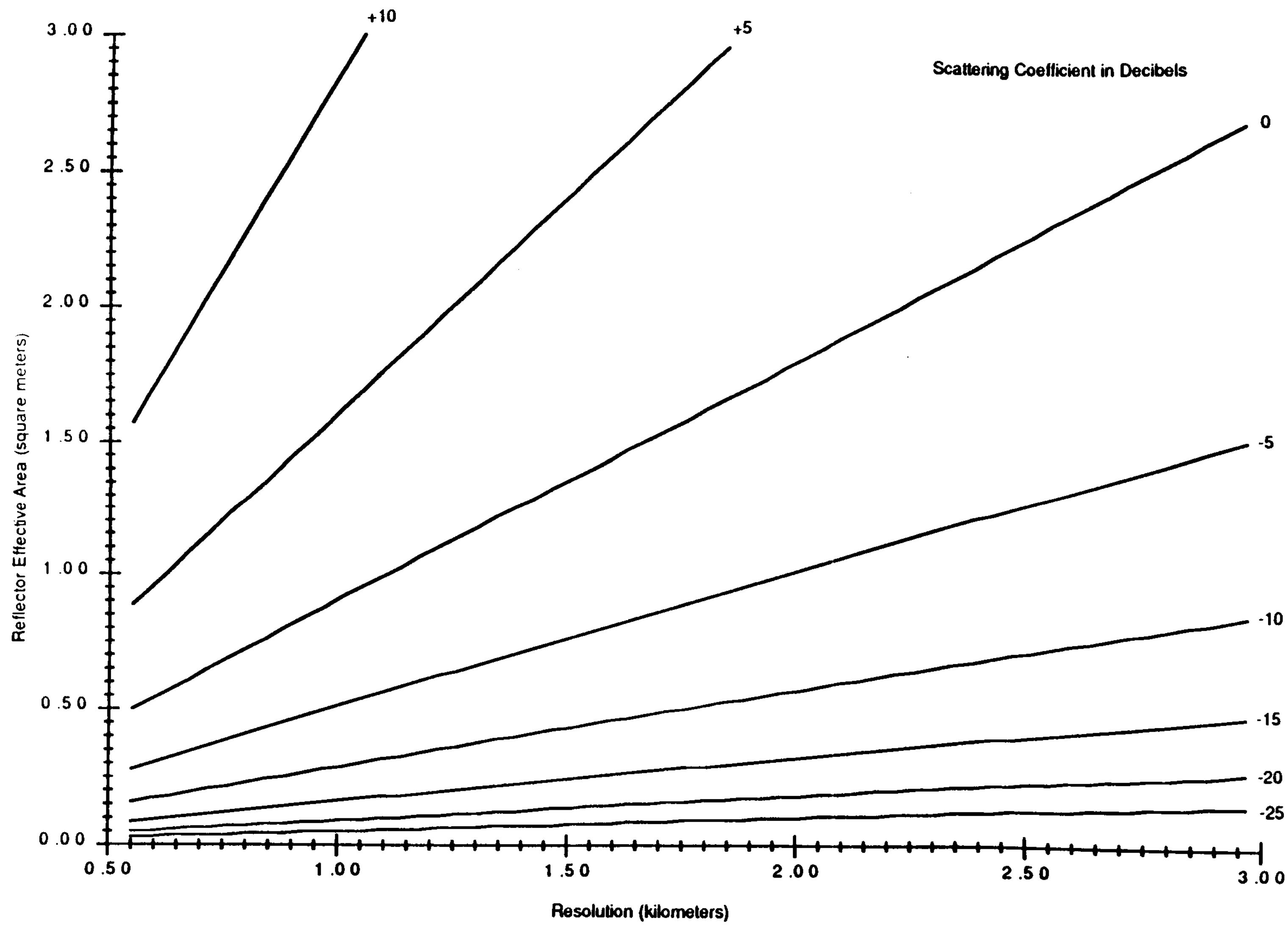
Received Power 15% Above Normal Backscatter, 1 Kilometer Resolution, 60 Degree Depression Angle



Graph 4. Triangular Trihedral Edge Dimension vs Scattering Coefficient for Various Frequencies
Received Power 15% Above Normal Backscatter, 1 Kilometer Resolution, 60 Degree Depression Angle



Graph 5. **Square Trihedral Edge Dimension vs Scattering Coefficient for Various Frequencies**
Received Power 15% Above Normal Backscatter, 1 Kilometer Resolution, 60 Degree Depression Angle



Graph 6. Required Passive Reflector Effective Area vs Resolution for Various Scattering Coefficients

34.55 GHz, 60 Degree Depression Angle, Power Received 15% Above Normal Background

Appendix A

SECTION C
DESCRIPTION/SPECIFICATIONS/WORK STATEMENT

C.1 STATEMENT OF WORK

Background

A two-session World Administrative Radio Conference will be held in 1985 and 1988 to guarantee, in practice, equitable access to the geostationary satellite orbit by all nations. Studies and analyses are needed in order to develop U.S. positions for the 1985 conference which will decide which radio services and bands will be planned.

The TOPEX project is faced with potential radio frequency interference problems due to a need to use an unallocated frequency for a second altimeter channel. This problem needs to be analyzed, as well as potential mutual interference caused by instruments planned for TOPEX and advice provided to the project.

In view of the many new frequency allocations for remote sensors resulting from the 1979 World Administrative Radio Conference (WARC), there is an immediate need to determine compatibility between passive sensors and active radio services operating in adjacent and harmonic frequency bands. The results of these studies are needed for submission to the international Radio Consultative Committee (CCIR) at the interim meetings of its XVI cycle.

Statement of Tasks

The Contractor shall provide the necessary personnel, facilities, and materials in order to continue performance of the following task:

TASK 1 - ADJACENT AND HARMONIC BAND ANALYSIS

Interference studies involving passive sensors, to date, have not considered potential interference from active services in adjacent and harmonic bands. The purpose of this study is to analyze the frequency allocation tables adopted by 1979 WARC to determine whether passive sensors operating in allocated bands might be jeopardized by active services in adjacent and harmonic bands. In addition, if such interference is found to be harmful, practical filter characteristics shall be determined, if feasible, which could be incorporated into both sensor and transmitter designs to eliminate harmful interference. The following studies shall be performed:

1. Analyze the Final acts of the 1979 WARC to determine potential adjacent and harmonic band interference situations. Quantify the interference that is expected in each case.

2. Determine filter characteristics used in typical state-of-the-art passive sensor designs. Further, determine if improved sensor filter characteristics are feasible and the amount of increased out-of-band rejection that might be achieved.

3. Determine filter characteristics used in typical state-of-the-art transmitters in services where interference problems have been identified. Further, characteristics are feasible and the amount of increased out-of-band rejection that might be achieved.

4. Develop filter characteristic standards for each band where adjacent or harmonic band interference problems are identified which, if adopted by passive sensors and transmitter designers, would alleviate the interference.

Preliminary investigations into the questions of adjacent and harmonic band operations have been reported by the Jet Propulsion Laboratory in "Feasibility of Simultaneous Operations of the Passive Microwave Sensors and Active Services Occupying Adjacent Frequency Bands", JPL, May 1982. This earlier work shall be utilized in the instant studies.

TASK 2 - ANALYSIS OF IMPACT OF SENSOR RESOLUTION ON INTERFERENCE

Sharing models for passive microwave sensors and other services operating in common frequency bands have been developed and adopted by the CCIR. The data lost to passive sensors due to interference has been calculated using projected sensor resolution to satisfy future needs of the scientific community. Current sensors have resolution considerably poorer than that used in the earlier analyses. The contractor shall perform a parametric analysis of each frequency band allocated for passive remote sensing to determine the effect of resolution on sensor data loss.

TASK 3 - PREPARATIONS FOR 1985/88 WORLD ADMINISTRATIVE RADIO CONFERENCE (WARC)

The International Telecommunications Union (ITU) will convene the first session of the geostationary orbit World Administrative Radio Conference during 1985. The second session will be held in 1988.

The contractor shall support NASA preparations for the WARC with regard to the Earth Exploration Satellite Service. Specifically, the contractor shall review and revise existing documentation, perform analyses as required, prepare U.S. input documents for the WARC, and review foreign documents.

TASK 4 - PREPARATIONS FOR CCIR STUDY GROUP 2 FINAL MEETING

The contractor shall support NASA preparations for the CCIR Study Group 2 final meeting in the area of the Earth Exploration Satellite Service. The contractor shall modify CCIR draft reports based on results at the CCIR interim meetings, perform new analyses as required, prepare new reports including one which gives the analytical results obtained in Task 2.

TASK 5 - DEVELOP PERFORMANCE CRITERIA, INTERFERENCE CRITERIA, SHARING CRITERIA, AND COORDINATION CRITERIA

The criteria needed for sharing and coordination between the Earth Exploration-Satellite Service and other radio services have not, to date, been developed. Depending on the decisions made by the 1985 WARC, criteria to apply to several bands and services could be needed before 1988. Criteria are needed in any event; only the need date is in question.

The contractor shall study the general subject of criteria for the Earth Exploration-Satellite Service. A plan shall be generated to show how the needed criteria might be developed. Suitable criteria shall be developed for the 8025-8400 MHz data acquisition band. In addition, suitable criteria shall be developed for one passive microwave sensing band and one active microwave sensing band. Appropriate documentation in the form of CCIR recommendations, reports, and entries in Appendix 28 of the Radio Regulations shall be prepared which would put the criteria into effect.

TASK 6 - SPECTRUM ENGINEERING FOR NASA MICROWAVE SENSOR PROJECTS

The contractor shall analyze potential interferences between NASA microwave sensing instruments and other systems using the radio spectrum. The contractor shall advise the NASA projects with respect to the best choice of operating frequencies and predicted levels of interference, both received by and caused by the sensor.